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Human Reactions to Experimentally Induced Impact Forces*

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THIS paper applies to any field of medicine where the application of force causes injury. Current investigations in the Acceleration Unit at the Naval Medical Research Institute have implications which go beyond the bounds of aeronautics. Applications of these studies to many types of trauma are now evident. During the war, the problem of aircraft crashes was paramount, but because of circumstances it was a difficult problem to attack except from a preventive angle.

Within the past ten months studies of a fundamental nature have been undertaken on mechanical forces. These forces can be thought of as the etiologic agent of trauma. They have a definite structure just as bacteria or known viruses possess certain characteristics. A force can be described by its magnitude, duration, and pattern. A force even has an "incubation period" in that a certain time is required before its effects become clinically apparent. True, this incubation period is measured in milliseconds rather than days or weeks, but none-the-less it is a definite period. Forces, if large enough, may cause injury, or, if small, may be without physiological effect. They can be applied for long durations. Forces may be smoothly applied or may possess many irregularities or oscillations. The type of force greatly influences the sequence which follows, and a resistance to some types of forces can be developed. The treatment with which we are concerned is mainly that of prophylaxis, or alteration of the force so that the individual can tolerate a given amount of energy without injury. All these circumstances determine the effect of a given force upon the human.

It is known that some individuals have survived forces calculated to exceed 200 G.[5] These are usually referred to as "lucky" or "miraculous" escapes. But if one dares the damnation of superstition, it is evident that in the scientific world, luck or a miracle do not exist, per se. We feel that in such cases a peculiar train of physical events occur, rare to be sure, but none-the-less effective in permitting survival of an otherwise fatal accident.

One of the approaches to this problem has been to study these so-called lucky sequences with an ultimate goal of devising an apparatus or garment which can channel the force of a given acceleration into a preferred path and prevent injuries and fatalities.

It is reasonable to assume that the accelerations involved in aircraft crashes are not uniform. Therefore, in considering any procedure for protecting individuals from injury during such crashes, one must of necessity interpret the simple physical formulae for acceleration with caution.

One fact which stands out in crashes of military aircraft is that up to reasonably high forces (about 60 G), despite destruction of the wings, tail, under-carriage, and engine, the cockpit usually remains intact. (Fig. 1.) The fear of telescoping of the aircraft to crush the occupants, so common in the early days of aircraft construction, no longer exists in most military and a fair number of civilian aircraft. The aircraft industries have altered the pathogenesis of injury by more modern methods of construction so that personnel are now injured or killed in crashes by being flung about within an intact cabin or cockpit area. This factor is most evident in crashes aboard aircraft carriers where the entire sequence from before, during, and after a crash is followed by observers aboard the ship and can be photographed in slow motion. A study of these sequences has shown

* The information contained herein is that of the author and not necessarily the policies of the United States Navy.

that it should be possible to protect individuals within the cockpits of aircraft which remain intact during crashes involving large forces. This, of course, is of great importance to personnel flying in aircraft and not actually in control, such as the passengers in a transport plane.

Figure 1.—Corsair which crashed during field carrier practice from 50 ft. at approximately 80 miles an hour. The wings, tail, engine and under carriage are demolished yet the cockpit is intact.

In the summer of 1945, the impact decelerator[1] was devised and with this instrument we have been able to study the reactions of humans under impact forces. All investigations were carried on, using ourselves and other volunteers as subjects.

In military aircraft, the pilot is secured in his seat by means of a restraining harness, i.e., shoulder straps and seat belt. If a plane is involved in a crash, sudden deceleration occurs, the plane stopping rapidly, usually within ten to forty feet. Provided the seat remains secured to its foundations, the individual is thrust against the shoulder straps and seat belt. Thus, the force of deceleration is applied largely to the individual's thorax and abdomen by means of this restraining device.

A similar effect may be obtained by suddenly jerking the restraining harness back against the individual. This enables the subject to receive an impact force with relatively little motion so that the investigator can closely observe him throughout the exposure. I can tell you that this was a most important factor during these initial studies for we were embarking on an entirely new field with little previous experience to afford any assurance as to the immediate outcome or as to injuries which might develop at some later date.

To do this, the impact decelerator was conceived in its rather simple form. To produce the necessary impact force, falling weights were used (Fig. 2). The weights are raised to a predetermined height and, upon a given signal, are released. They are arrested at the bottom of their fall by a plate fixed to a 65-inch steel rod, which then transmits the force back up the rod through the restraining device to the thorax and abdomen. Physiological measurements of respiration, electro-cardiographic tracings, ear pulse, ear opacity, peripheral pulse configurations, blood pressure and intra-abdominal pressures may be recorded simultaneously with the physical data of the force and time.

The respiratory pattern has been successfully recorded by inserting a thermo-couple, appropriately shielded, in each nasal air-way (Fig. 3). These elements are small, possess little inertia because of their small mass (they weigh less than 5 grams each) and they are extremely sensitive. During inspiration, the thermo-couples are exposed to the temperature of the environmental air. During expiration they record the temperature of the air coming from the lungs. Mouth breathing does not materially alter the pattern although nasal breathing is preferable.

The use of electrical wire strain gages has proven quite a boon in measurement of small displacements. A wire strain gage consists of fine wire placed against a metal surface so that small bending movements of the metal surface will change the resistance of this wire. With an appropriate electronic device these small movements of the metal surface can be recorded. Such a device can be placed over an artery and the pulse configuration can be easily detected. This same device can be used to measure impact pressures, cardiac impulse, blood pressures, and a large number of other physiological phenomena which are adaptable to its peculiarities.

The ear opacity and ear pulse are measured by detecting the amount of light transmitted through the ear to a photoelectric cell. The changes in the

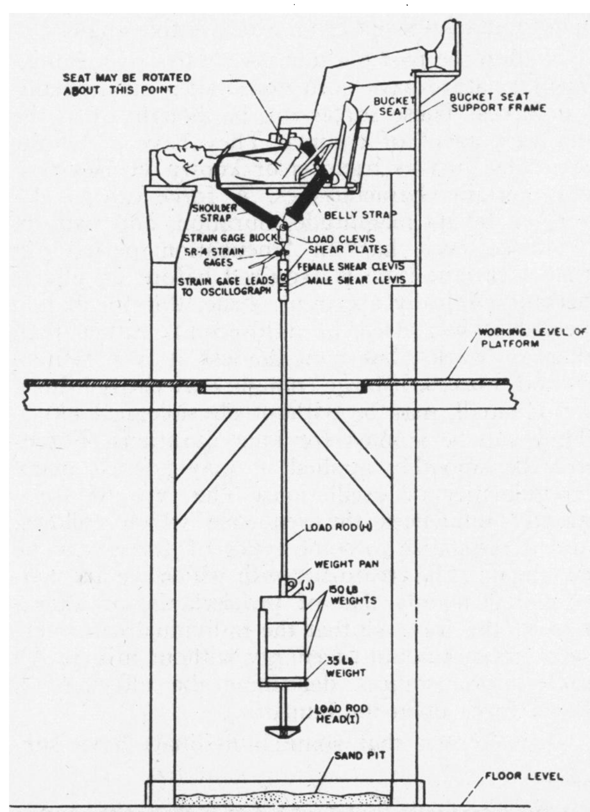

Figure 2.—The Impact Decelerator.

amount of light transmitted are a reflection of the volume of blood and pulse characteristics within the ear at the moment.

It should be emphasized that the stresses produced by airplane crashes and by the impact de-

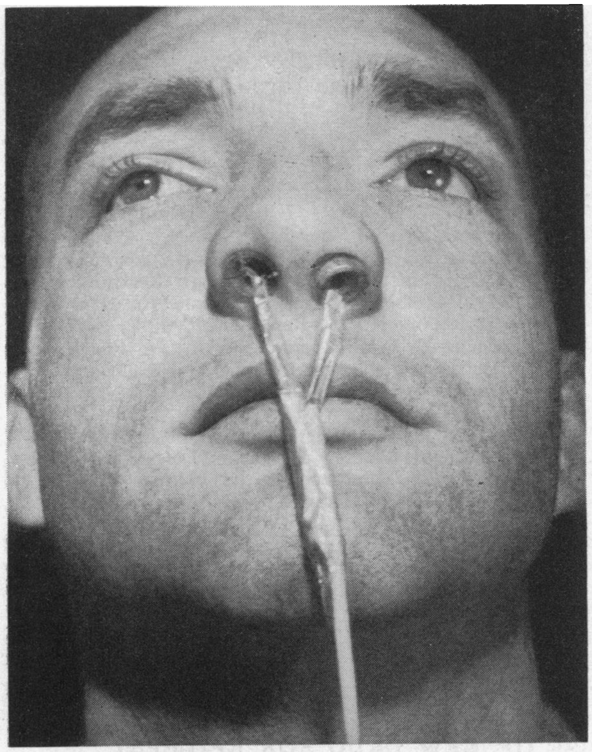

Figure 3.—Illustration showing plastic cylinders containing thermo-sensitive wire which are inserted into the external nares and are used to record the respiratory pattern.

celerator are comparable, but they are not necessarily identical. When more elaborate investigative methods (such as those involving human catapults, etc.) are available, it will be possible to duplicate more exactly the types of linear accelerative forces occurring in airplane crashes. Until that time the impact decelerator offers a highly useful and convenient technique for studying some effects of these forces.

The impact decelerator applies the forces directly to the subject. In an aircraft crash the forces are applied first to the aircraft structure and transmitted to the subject only through the seat and its attachments to the restraining devices. During such transmittal of force, there is undoubtedly an absorption of energy in the aircraft structure so that in all likelihood the force applied to the subject is less than the initial force at the point of the impact of the aircraft.

Studies at the Acceleration Unit have shown that it is possible to improve one's tolerance to impact forces. Using the decelerator it has been shown that with the current regulation harness the human subject can tolerate approximately 2,000 pounds peak impact force delivered within 0.15 second. The area of the current regulation harness is 76 square inches applied to the average thorax and abdomen. When this area of coverage is increased to 156 square inches by the use of a vest-type restraining harness, the tolerance limit is then increased to 3,300 pounds. Beyond this point we have seen ligamentous detachments, muscular and costochondral separations, and hematomas into muscle groups. These findings together with untoward physiological changes are used as the criteria for the limit of tolerance to impact forces.

It then became evident that if any significant increase in protection against impact forces was to be attained, it would take more than just increase of area and distribution of force. It had been shown in previous studies that the distribution of the force in the current regulation harness was not uniform despite the fact that the straps themselves were of uniform width. (Fig. 4.) Thus the greatest force was concentrated at an area in the vicinity of the umbilicus near the coeliac plexus which as you know is quite sensitive to impact forces, and can easily produce temporary incapacitation. During water landings at sea, pilots have been observed in the cockpit to be dazed and, when the plane sinks, to make no apparent effort to escape. The same applies to the fire hazard following crashes ashore. When these individuals are recovered, often little if any positive findings other than simple drowning or burns can be made. We feel that it is possible that these individuals have been momentarily stunned by a concentration of the impact in the neighborhood of the coeliac plexus despite the fact that the

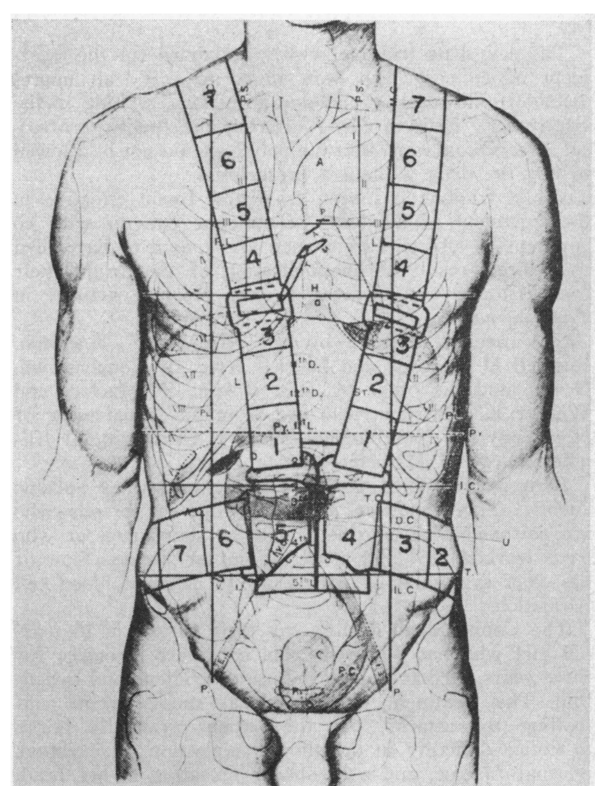

Figure 4.—Composite schematic drawing to illustrate the pressure distribution. The impacts produced maximal pressure forces at positions 6 and 7 on both shoulder straps. The maximal pressure areas on the seat belt were found at positions 4 and 5.

force of the crash is not excessive. Therefore, it is necessary to find some way to equalize the distribution of the force over this increased area to prevent concentration at certain vital points. This can be obtained by utilization of a material which will allow the body to form-fit into the harness during the impact.[2]

Further investigations on the impact decelerator, including high speed cinematography, afforded an opportunity to observe the effects of the early part of the impact. The rate of loading was found to bear a critical relationship to the subject's tolerance toward maximal loads.[3] Rapid applications of the force, attaining a peak in less than 30 or 40 milliseconds, were uniformly disliked. In general, the slower rates of loading were preferred. An optimal rate of loading exists, however, since slowing the rate of loading too much may cause a reduction in tolerance.[4]

SUMMARY

1. The possibility exists of surviving high impact forces in crashes in military aircraft.
2. The magnitude and duration of a given force in part determines its effect upon the body. Increasing the area of distribution of a force reduces the untoward effects upon subjects.
3. Forces should be distributed to those areas of the body more capable of withstanding these forces.
4. The rate of loading bears a critical relationship to the tolerance of the subject to impact forces.
5. Small oscillations and irregularities in a force are disagreeable to subjects.
6. Force is the etiological agent of trauma, and as such requires much further investigation of a fundamental nature.

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FIVE PHYSICIANS WARN AGAINST USE OF NEW DRUG FOR EPILEPSY

The new drug tridione, widely acclaimed for the treatment of epilepsy, has been found to carry an unpredictable toxic reaction and five physicians, writing in the September 7 issue of *The Journal of the American Medical Association,* warn that the public should not be allowed to buy the drug without a prescription.

While tridione has been tried and found effective in the treatment of hundreds of epileptic patients with no apparent ill effects, two women are known to have died as a direct result of administration of the drug. Their case histories are reported in two separate articles in *The Journal.*

One case is reported by Drs. Francis F. Harrison, Roswell D. Johnson and Darrell Ayer, of Cooperstown, N. Y., and the other by Drs. Roland P. Mackay and Werner K. Gottstein, who are from the Department of Neurology and Neurological Surgery, University of Illinois College of Medicine, Chicago.

Both patients died from a disease known as aplastic anemia. This condition often develops in persons who are poisoned with benzine or similar substances, or who have worked too long with radium or x-rays. One of the chief symptoms of the disease is deficient blood cell formation.

The Cooperstown doctors say their patient, a 16-year-old girl who had suffered from convulsive seizures for three years, died following the use of tridione and hydantoin. The treatment, they say, was successful in controlling the attacks, but the patient gradually began to notice difficulty in breathing, palpitation on exertion, unusual fatigue, and a throbbing sensation in her head. The patient later suffered hemorrhages. All the measures used to prevent and treat infection, stimulate blood cell production and arrest bleeding proved of no value.

The two Chicago doctors say their patient was a 23-year-old unmarried woman who had suffered convulsive seizures since she was five years old. After repeated major convulsive seizures, tridione was administered. Later she suffered from severe headaches, with vomiting, generalized weakness and fatigue. Autopsy revealed extensive hemorrhages throughout the body.

In discussing the case, Drs. Mackay and Gottstein say:

"There is little doubt that death was due to tridione. The only drugs used by the patient for ten months prior to her death were phenobarbital and tridione, and she had taken phenobarbital almost constantly for 19 years without ill effect.

"The destruction of the elements of her blood was delayed but abrupt. The acute onset of her illness came only after ten months, but it came suddenly. These facts strongly suggest a progressive accumulation of the drug, or of toxic fractions of it, in the body. As late as two days before her admission to the hospital she walked several blocks without distress. The process was therefore catastrophic and apparently uninfluenced by vigorous treatment."

After outlining several suggestions to other physicians on the use of tridione, the Chicago doctors say:

"Unprescribed sale of the drug to the public should not be allowed. The present enthusiasm for tridione, both among the profession and with the public, is very great, because of the glowing accounts which have appeared in the scientific and public press, and even on the radio. The public knows the drug by name and can buy it on the market. A doctor's prescription is recommended on the company's labels and should be required.

"Finally, further research with tridione and related substances must be carried out. Despite the unfortunate toxic effects of tridione revealed in this case, the drug offers great promise for effective control of the most stubborn of all convulsive disorders, if its dangers can be avoided. This promise should be fulfilled."